PATENT SPECIFICATION 1,044,789

DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Non-Contacting Microwave Line Stretcher.

We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of Connaught House, 63 Aldwych, London, W.C.2, England, (assignees of JOHN HESSLER, Jr.), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to microwave transmission lines having variable electrical length and non-contacting transducers operating in the microwave and higher frequencies.

A microwave line stretcher is a mechanical device for changing the physical or effective electrical length of a high frequency transmission line. While line stretchers may have many uses, one particular use is to steer the pattern of an antenna. Sometimes this pattern must be steered very quickly to follow a fast moving object. Therefore, the mechanical device must be quickly and easily adjustable.

One way of adding physical length to a high frequency transmission line involves telescoping tubes which lengthen or shorten wave guides included in the line. These tubes may be made in the form of a simple telescope; or, they may be folded to provide a trombone-type slide. Either way, the inner and outer slides must fit snugly to avoid high frequency losses. This snugness usually prevents rapid slide motion and causes excessive wear. Also, thermo-electric potentials develop across the contact between the slides to cause noise. Thus a telescoping tube is totally unsuited for use where extremely fast response and low noise operation is required.

Another way of changing the physical length of a microwave transmission line involves the use of a movable short which is a quarter wave length open line followed by a quarter wave length shorted series line slidably positioned in a wave guide or other transmission line. If the shorted line is not used as a one port stub, but is used as a two port line stretcher (i.e. with input and output), two stubs must be used with a "perfect" quadriture hybrid network. In practice quadriture hybrid networks are far from perfect with multiple path lengths resulting.

The aim of this invention is to provide line stretchers having low friction and devoid of all rubbing contacts.

According to the invention there is provided a microwave transmission line having variable electrical length including a movable inner conductor and an outer conductor having one end formed into a pickup cavity, a part of the movable inner conductor being within the pickup cavity and resonated therein to a predetermined frequency, a pickup mounted within the pickup cavity and connected to an external connector non-contactive with and electrically coupled to the movable conductor, and means to move the movable conductor through the cavity so as to reduce its active length.

The invention will now be described with reference to the accompanying drawings in which:—

Fig. 1 diagrammatically shows why a line stretcher is necessary and desirable;

Fig. 2 is a perspective view (with a broken away section) of a preferred embodiment of the invention incorporating a printed circuit card slidably mounted for linear movement;

Fig. 3 is a perspective view of a second embodiment of the invention incorporating a printed circuit card mounted for rotary motion;

Fig. 4 is a perspective view of the cavity

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the two transmission lines 50, 54 in this cavity are incorrect for resonating at the correct circuit Q's when terminated directly in the strip-line of Figure 6 and the coaxial line. Therefore, an impedance matching coaxial line section 56 is provided to transform the impedance of the coaxial line to a value which will resonate pickup 50 in cavity 40 with the correct Q. Similarly, an impedance of the strip line 54 in cross section Fig. 6 to a value which will resonate strip 54 in cavity 40 with the correct Q. When both resonators in cavity 40 are resonated at the proper Q's, an impedance match is achieved between coaxial line 29 and strip-line 54 in cross section Fig. 9.

To assure proper resonance of strip 54 in cavity 40, a non-contacting short circuit terminates printed strip 54 at the same end of cavity 40 which is entered by coaxial line 29. The term " non-contacting " means that the card 31 does not physically touch the short or stub line. In greater detail, this device consists of a quarter wave length open line and a quarter wave length shorted line formed by a pair of conductor plates (such as beryllium copper) bent into an L-shaped section as shown at 44, 45. These plates are secured in the cavity 40 (in any suitable manner) to form the non-contacting short. The short circuit at points 46, 47 of the line formed by the cavity and plates reflects an open circuit at points 48, 49 which is in series with the impedance of the cavity 43. This short circuit at points 46, 47 transforms to the open circuit at points 48, 49. The open line where the plates are parallel to the printed circuit card 31 transforms the open circuit at points 48, 49 into a short circuit at points 44, 45. The shorted line or stub is one quarter wave length long to further improve the impedance matching of the coaxial cable into the coupling cavity, by providing a perfect short circuit.

Mounted in the cavity 40 is a radiant energy pickup 50 which is positioned close to, but does not physically contact, the printed circuit card 31. The pickup is a flat plate of electrically conductive material (such as beryllium copper) having a lug or terminal at each end to facilitate an electrical connection. The coaxial cable 29 is connected to one lug 51 through coaxial cavity 56, and the system ground is connected to the other lug 52. The effective length (shown by the dashed center line 53) of the copper plate 50 is one quarter wave length of the desired center frequency. When the pickup is energized at radio and higher frequencies, energy is emitted into the cavity 37 in the form of electromagnetic waves, and since no physical contact occurs between the pickup and the printed circuit card contact noise does not develop and contact material does not erode.

The general configuration of the line stretcher and the manner in which the cross sectional geometry of the cavities changes along the length of the housing will be apparent from a study of Figs. 5—10. That is, beginning at the lefthand end Fig. 6, the space 38 is thicker than the printed circuit card 31, the thickness t being to provide a desired characteristic impedance, such as 50 ohms. Moving along the housing to the right in Fig. 7, we find the impedance matching cavity 41 for printed circuit strip 54, and cavity 41^1 for strip 55. Moving still further to the right in Fig. 8, we come to the principal coupling cavities 40, 40^1 for giving entrance and exit to lines 29, 30 of the coaxial cable and housing the pickups 50, 50^1. The distance E between where the cables 29, 30 attach to the pickups 50, 50^1 is made as large as practical to minimize crosstalk. Between the coaxial line 29 and pickup 50, is located a coaxial impedance matching cavity 56. There is a similar cavity 57 for line 30. Continuing to the right in Fig. 9, we come to the non-contacting short 44, 45 on the strip 54 cavity 42 and the non-conducting short 44^1, 45^1 on the strip 55 cavity. Moving still further to the right in Fig. 10, we find RF absorbing material 58, 59 for strip 54 and 60, 61 for strip 55. This material makes a low impedance back load that improves the electrical performance of the short 44, 45.

The nature of the printed circuit card construction will be apparent from a study of Fig. 11. That is, the printed circuit card includes a sandwich of two sheets of dielectric base material 62, 63 having good wear resistant qualities such as epoxy fiberglass, for example. Deposited on one of these sheets of fiberglass is a conductive material 54, such as copper, which is etched or eroded away through any well known printed circuit card construction techniques. Thus, the printed circuit card comprises a sandwich of dielectric supporting material separated by a printed conductive strip. The advantages of this construction are: wear resistance, elimination of accidental short circuits, and increased strength.

To reduce friction within the housing and facilitate movement of the printed circuit card, the upper and lower ends of the card supporting space 38 are rounded as shown in Fig. 12. These rounded ends provide guideways in which the printed card slides. Since the guideways are rounded and the edges of the printed circuit card are squared, friction forces appear only at the relatively small working area indicated by the arrows F, G. Thus, it is apparent that the card movement causes a minimum of friction and allows a fast responding mechanical action.

In keeping with one aspect of this invention, the printed circuit card includes a conductive strip having a geometry such that the effective length of the conductive strip increases when the card is moved to the right

(as viewed in Fig. 13) and decreased when the card is moved to the left.

As shown in Figs. 13, 15, the printed circuit card 31 has a strip line conductor 54, 55 deposited thereon. This strip line is shown in Fig. 13 (for lateral motion in the embodiment of Fig. 2) as including two spaced, parallel, straight sections joined at one end 65 to provide a generally U-shaped continuous strip line conductor. In the rotary embodiment of Fig. 3, the printed circuit card has a pair of concentric arcs 66, 67 shorted at one end 68, as shown in Fig. 14. In either embodiment, the pickups 50, 50^1 are positioned parallel to and spaced from the conductive strip. The major portion of the pickup should overlap and generally conform to that portion of the strip line which is immediately adjacent, or just beneath the pickup, as shown in Fig. 13.

Since the coaxial cable 29 and a ground potential must be connected to opposite ends of the pickup 50, it is convenient to provide lugs or terminals which give the pickup a somewhat arcuate shape. It may be desirable to rivet or swage the center conductor of a conventional coaxial cable coupler to the lug 51 on one end of the pickup 50. The other end 52 of the pickup may be secured to the housing 34 which is at ground potential.

The distance *h* between the pickup 50 and the strip line 54 represents a compromise between expense of manufacture and band width requirements. On the one hand, it is desirable to place the pickup as far as possible from the strip line so that the manufacturing tolerances will not be critical. On the other hand, it is desirable to place the pickup as near as possible to the strip line to pass a maximum bandwidth. In one particular device, a convenient compromise occurred when the pickup was secured .040″ from the strip line 54.

By an inspection of Fig. 13 it will be apparent that the effective length of the strip line 54, 55 is approximately twice the length L. That is, the effective length is the length between the pickups. Thus, beginning at pickup 50, and continuing around the strip line to the pickup 50^1 there is a strip of conductive material about 2L long. If the printed circuit card is moved to the left in the direction of the arrow C, obvisously the effective line becomes shorter. If the card is moved to the right in the direction of the arrow D, obviously the effective line becomes longer. Hence, the coaxial cable 29, 30 is stretched or shortened by laterally moving the printed circuit card 31.

The transfer of energy from the coaxial cable 29 to the strip line 54 or the transfer of energy from the strip line 55 to the coaxial cable 30 is via a radiant energy field set up between the two resonant strips 50, 54 in cavity 40 or 50^1, 55 in 40^1. For an understanding of this feature, reference is made to Fig. 16 which shows the electrical equivalent of the resonant strip 54 in cavities 40, 41 and the coaxial cavity 56 and pickup 50 of cavity 40. In greater detail the coaxial cable is constructed to have a specified characteristic impedance. The strip transmission line 54 in cross section Fig. 6 is designed to have the same characteristic impedance as coaxial line 29. Strip 54 in cavity 40 has a different characteristic impedance. Electrically interposed between the stripline of cross section Fig. 6 and cavity 40 is the intermediate strip cavity 41 which transforms the impedance of strip 54 in cross section Fig. 6 to a value which will cause strip 54 in cavity 40 to resonate with the required circuit Q. Similarly, cavity 56 is provided to transform the impedance of coaxial line 29 to a value which will resonate pickup strip 50 in cavity 40 with the correct Q. When the correct Q is achieved for the two circuits, an impedance match occurs between the coaxial line 29 and the strip transmission 54 of Fig. 6. Similar cavities are provided for cable 30. Each cavity is a quarter wavelength long at the desired center frequency. Since the two quarter wavelength sections 40, 41 of strip 54 are joined mechanically to provide a single resonator of a half wavelength in length, radiant energy in sections 40, 41 forms a standing wave 69 of one half-cycle of the center frequency of the transmitted band, Fig. 16. A similar half-wave 70 is shown for pickup 50 and cavity 56. This radiant energy wave transmits energy from the pickup 50 to the strip 54 in cavity 40 through electromagnetic coupling. The output signal is transmitted through cavities 40^1 containing pickup 50^1 in a similar manner. The input and output terminals can be reversed.

The relation between the two strip resonators 54, 50 in cavity 40 is such that the radiant energy in the input strip resonator 54 bears a relation to the radiant energy in the output pickup 50 which is described by the following mathematical equation:

$$K_{12} = \frac{4(Z_{oe} - Z_{oo})}{n\pi(Z_{oe} + Z_{oo})}$$

$$Z_o = \sqrt{Z_{oe} Z_{oo}}$$

n = Determined in the Q computation

where:

K_{12} = the filter coupling coefficient between the strip 54, pickup 50 in cavity 40

Z_{oe} = even mode characteristic impedance of the strip 54 or pickup 50

Z_{oo} = odd mode characteristic impedance of the strip 54, pickup 50

n is approximately 2 since total resonator 40+41 or 50+56 is two quarter

wave lengths long; however, the characteristic impedances of the two sections in each resonator are not equal and the number n will not be exactly 2.

and:

Z_{oe} of the printed circuit strip 54 is made equal to Z_{oe} of the pickup 50.

Z_{oo} of the printed circuit strip 54 is made equal to Z_{oo} of the pickup 50.

Note: When $\frac{Z_{oo}}{Z_{oe}} = .24$, the manufacturing tolerances are best.

The circuit values should be selected to make K_{12} a maximum practical value while maintaining Z_{oo}/Z_{oe} close to. 24. If the "Q" (figure of merit of a loaded circuit) of the input strip 54 and cavity 40, 41 equals Q_1 and the "Q" of the output coaxial cable 29 and resonator 50, 56 equals Q_2, the voltage standing wave ratio (VSWR) of the strip line to coaxial transducer is described by the following mathematical equation:

$$VSWR = K_{12}^2 Q_1 Q_2$$

The circuit values should be selected to make the VSWR=1 for Butterworth response or slightly above 1 for Chebishev response.

Where $Q_1 = Q$ of combined 40, 41, strip 54
$Q_2 = Q$ of combined 50, 56
and $Q_1 = Q_2$ for proper design.

To design the coaxial to stripline transducer of the line stretcher to have a Chebishev response, the following procedure may be followed:

1. Compute the Z_{oo} and Z_{oe} of an assumed configuration
2. Assume a maximum voltage standing wave ratio over the band of $r = 1.02$
3. Required resonator Q

$$Q_1 = Q_2 = \frac{n\pi}{4} \; \frac{Z_{oe} + Z_{oo}}{Z_{oe} - Z_{oo}} \sqrt{r}$$

4. Definition of Q

$$Q_1 = Q_2 = \frac{n\pi}{4} \; \frac{Z_o}{R_s}$$

Where $Z_o = \sqrt{Z_{oe} Z_{oo}}$

R_s = Mathematical equivalent resistance

5. Characteristic impedance of impedance matching sections 41, 56

$$Z_{om} = Z_o \sqrt{\frac{Z_{ot}}{R_s}}$$

Where Z_{ot} is the characteristic impedance of the strip 54 to compute 41 or of coaxial line 30 to compute 55

6. Mode number n

$$n = 1 + \frac{Z_o}{Z_{ot}}$$

7. Computation of Q_1 from equation 4

$$Q_1 = \frac{n\pi}{4} \; \frac{Z_o}{R_s}$$

8. Computation of band width over which the value assumed in step 2.

$$B = \frac{F_o}{Q_1} \sqrt{2(r-1)}$$

Where F_o = center frequency

9. If the band width calculated above is quite different than required, the value of VSWR for substitution into equation 3 is the following:

$$r = 1 + \tfrac{1}{2} \left(\frac{B\,Q_1}{F_o} \right)^2$$

10. If the above voltage standing wave ratio r is too high, it is necessary to change the configuration of the strip and cavities associated with 40 to obtain a higher value of K_{12}.

The use of suitable known servo or feedback mechanisms permits the line stretcher to be adjusted almost instantaneously to changing electrical needs of associated equipment. Additionally, the line stretcher provides greatly improved electrical characteristics because there are no contacts across which thermal potential differences can appear as noise. The coupling also virtually eliminates any standing wave reflections between the strip line and the coaxial cable. For example, with one particular device, it was found that the VSWR=1.09 when the band width was 12% of the transmitted center frequency (for one transducer only). The mechanical structure reduces the need for precision milling, grinding, or shaping by the

use of photoprocessing. Finally, the line stretcher provides a two port structure in which when one pickup is not used the device may be used as a one port stub.

While the principles of the invention have been described in connection with specific apparatus and applications, it is to be understood that this description is made only by way of example and not as a limitation on the scope of the invention.

WHAT WE CLAIM IS:—

1. A microwave transmission line having variable electrical length including a movable inner conductor and an outer conductor having one end formed into a pickup cavity, a part of the movable inner conductor being within the pickup cavity and resonated therein to a predetermined frequency, a pickup mounted within the pickup cavity and connected to an external connector noncontactive with and electrically coupled to the movable conductor, and means to move the movable conductor through the cavity so as to reduce its active length.

2. A microwave transmission line as claimed in claim 1 in which the pickup is resonated at the predetermined frequency, the junction between the pickup cavity and the remainder of the transmission line includes a matching cavity to match the impedance of the transmission line to the impedance of the pickup cavity, the pickup cavity wall opposite to said junction is extended to form the outer conductor of a coaxial stub line having the movable conductor as inner conductor, the coaxial stub having also an open circuit at the end remote from the pickup cavity, an electrical length an odd number of quarter wavelengths of the predetermined frequency and producing a non contactive short circuit of the movable conductor at the cavity wall.

3. A microwave transmission line as claimed in claim 1 or claim 2 in which the external connector includes a further matching cavity to match the impedance of the pickup cavity to the impedance of a connected line.

4. A microwave transmission line as claimed in either one of claims 1, 2 or 3 in which the transmission line is a movable strip conductor enclosed within and insulated from a conductive housing and the cavities and one conductor of the line are within the housing.

5. A microwave transmission line as claimed in any one previous claim including pickup cavities at each end of the line, the external connectors connected to the pickups being an input and an output connector respectively and the line being shaped so that movement of the movable conductor reduces its length between the pickups.

6. A microwave transmission line as claimed in claim 4 or 5 in which the movable strip conductor is a printed conductor sandwiched between two wider strips of insulation material, the edges of the insulation material sliding in grooves in the internal walls of the outer conductor and movably supporting the strip conductor.

7. A microwave transmission line as claimed in claim 5 or claim 6 including two parallel portions and a linking portion connecting the parallel portions and an outer conductor formed in a further cavity to accommodate the movement of the linking portion of the line.

8. A microwave transmission line as claimed in claim 5 including two concentric radial portions connected at one end, the movable conductor being a printed conductor sandwiched between two concentric discs of insulation material and the discs are mounted in the outer conductor pivotable about their centres.

9. A microwave transmission line substantially as described with reference to figures 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15 and 16 of the accompanying drawing.

10. A microwave transmission line substantially as described with reference to Figures 3 and 4 of the accompanying drawings.

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Chartered Patent Agent,
For the Applicants.

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FIG.1

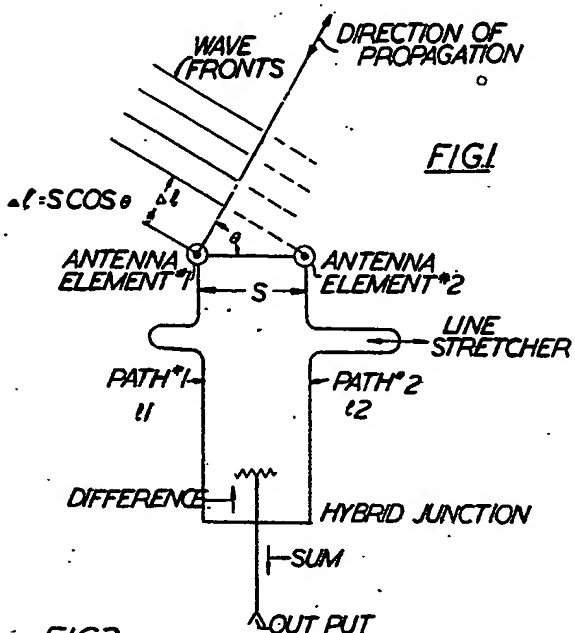

FIG.2

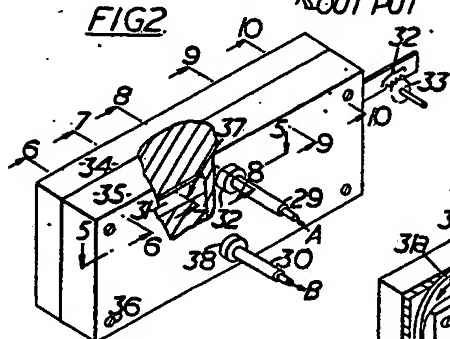

FIG.3

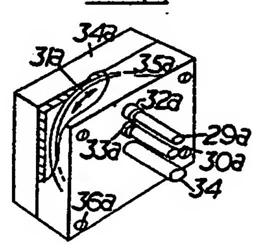

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FIG.4.

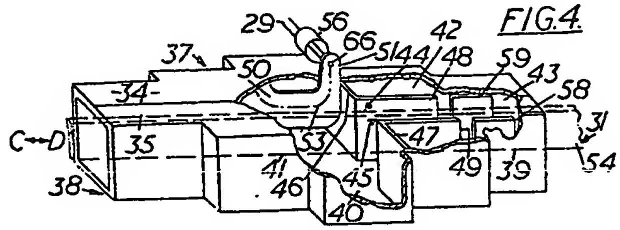


FIG.5.

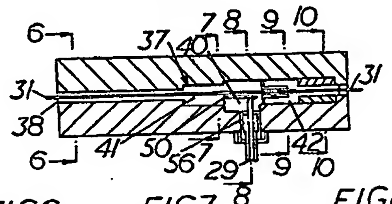


FIG.6.

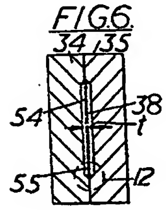


FIG.7.

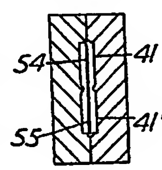


FIG.8.

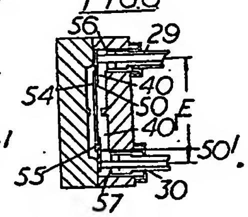


FIG.9.

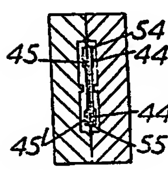


FIG.10.

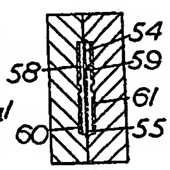
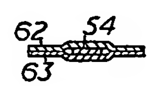


FIG.11.



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Sheets 2 & 3

FIG.4.

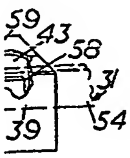


FIG.8

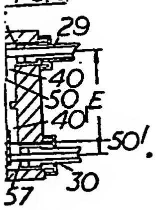


FIG.11

FIG.12.

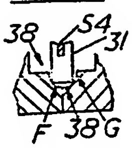


FIG.13.

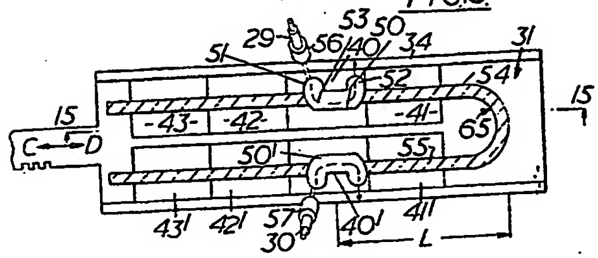


FIG.14.

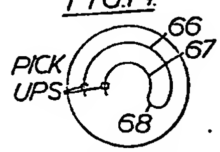


FIG.15.

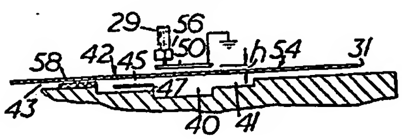
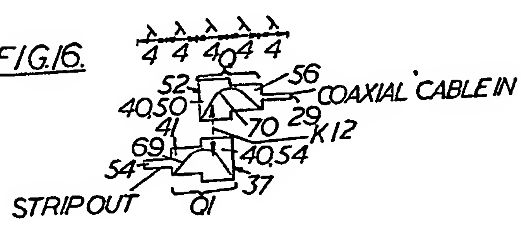


FIG.16.



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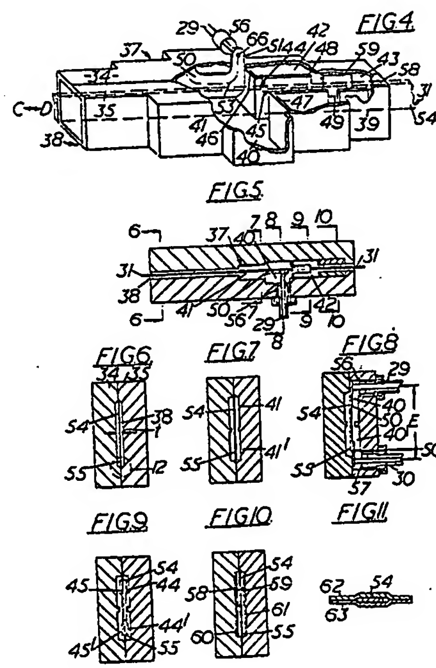

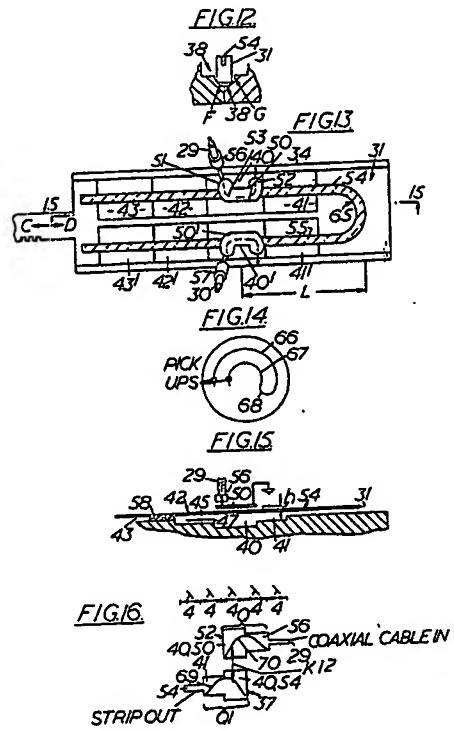

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